Environmental Monitors on Lobster Traps Phase VII: Validating Ocean Models

Final Report October 2012

Award number: 07-051

Period of performance: 06/30/08-08/31/12

Contact information of the principal investigator:

Jim Manning
NOAA/NEFSC
166 Water St
Woods Hole, MA
02543
508-495-2211 (office)
508-566-4080 (cell)
james.manning@noaa.gov

Other key participants:

Erin Pelletier, 207-985-8088, erin@gomlf.org
Gulf of Maine Lobster Foundation

Vitalii Sheremet, 508-548-3373, vsheremet@gso.uri.edu
University of Rhode Island

Dave Casoni, 508-224-3038, lobsterteacher@hotmail.com
Massachusetts Lobstermen

Abstract
In this final phase of NEC-funded eMOLT, the objective was to combine those aspects of the program that had worked most efficiently in the past (moored and drifting observations) to help validate ocean circulation models. The goal was to continue collecting hourly time series of temperature, salinity, and current at as many locations as possible for as long as possible. The result was a significant addition to the archive of web-served data that is now being compared to model simulations. Since the process involved aspects of engineering and the generation of computer code, the results are generally in the form of “tools” to do science rather than actual scientific results. Nevertheless, progress has been made in the melding of observations and models. Connections have been made between the people on the water, those behind the computer, and the numbers flowing back and forth between the two parties.

While multiple models were available over the course of the study, we chose to focus on the UMASS Dartmouth Finite Volume Coastal Ocean Model (FVCOM) output since it now has a 33 year hindcast of our entire study area. With nearly a 1000 drifter tracks in the database, comparisons are being made between observed and modeled tracks. Methods are also developed to compare both moored and drifter observations with model estimates on a hour-by-hour and point-by-point basis. These statistics can be binned by season or geographic zone. The model continues to improve since the inception of this project and eMOLT observations are also now being assimilated into the model to further improve its performance.

Introduction
The goals of the eMOLT project in general have been very much aligned with those of NEC. After nearly a decade of NEC funding through various phases of the project, there are now approximately 70 lobstermen on the Northeast Shelf who have not only contributed time and effort towards this project but are likely to continue for years to come. These individuals now understand the importance of long-term monitoring and the fact that the observations they make today are for the good of their children and their grandchildren. They are beginning to see the variations that occur over different time scales ranging from tidal to generational periods.

Given the complexity of the oceanographic conditions off our coast, it is clear that there will never be enough sensors installed to document all the processes that occur. The observations however serve to help numerical modelers simulate these processes and then be able to understand the mechanisms for variability. As our computer power increases, we continue to make progress in approaching the impossible reality of describing the entire suite of oceanographic processes. However, it is clear we need a healthy contribution of observations to help our models along.

Project objective and scientific hypothesis
As noted in the original proposal for this work and subsequent annual reports, our primary objective is to engage fishermen, students, and numerical modelers in a joint effort to validate simulations of New England's coastal current. The traditional means of ground truthing ocean circulation models typically involves deploying a few moorings at selected locations within the domain but this leaves

much of the complexity of the flow field unresolved. We choose to devise a system where low-cost instrumentation can be built and deployed by students and fishermen, respectively, at more locations. While traditional scientific moorings cost many tens of thousands of dollars to deploy and maintain, our observations cost at least an order of magnitude less, cover a much larger portion of the study area, and involve different sectors of the society beyond the academic scientists.

Given the topographic complexity off our coast, there is considerable spatial variability in the coastal currents which are affected by these bathymetric variations. There are evidently small areas of convergence and divergence that result in varying degrees of retention and dispersion of water parcels. Now that our circulation models have reduced their grid cells down to less than a kilometer resolution, they are capable of depicting some of these small scale features.

One example of a potentially important small scale feature is an area of relatively stagnant flow at the mouth of Buzzards Bay. While the semi-diurnal tides are fairly strong in this area, the residual means are near zero in contrast to a strong westward coastal current just offshore. Since lobstermen and scientist working together the last few years have found a higher concentration of egging female lobsters in this region, there is some discussion of the consequences. When lobsters release their eggs from the bottom, are they more likely to be caught in the westward coastal current or do they quickly ascend to the surface and then get affected up the bay in a wind-driven northeastward surface current? Given the dozens our drifters that have been deployed in this area in the last few years, we are beginning to understand the details of the mean flow as well as the temporal variability of small scale circulation patterns such as this feature south of Buzzards Bay. We may be able to explain the loss of young larvae from this region of the coast (Glenn et al, 2011).

Methods

The primary plan was to expand on the aspects of eMOLT that had worked well in the recent past (drifters, current meters) and compare these observations to numerical model output. Ten drifters were to be constructed by students and delivered to lobstermen to deploy. Fifty-bottom current meters were to be built and delivered to lobstermen along the coast. Data from the drifters, in particular, was to be shared with the High-Frequency Radar personnel at multiple labs so they could validate the surface currents derived from these systems. Salinity sensors were to be deployed by a few lobstermen in an attempt to correct for the difficulties experienced in eMOLT phase II. Web-based displays of all of the above were to be built and lobstermen were to be asked to comment on these pages. As the main components of our outreach effort, we had proposed both a day-long eMOLT event at the Maine Fishermen Forum as well as multiple presentations to students.

In the case of the drifters, participants were set up with the instrument in varying degrees of completion. Some received the drifters ready-to-deploy. Others either got a “kit” from us or, in the later years, actually built the drifters themselves with our specification document and transmitters. In the case of at least one group at the Roger Williams University, drifters were constructed entirely on their own using alternative cell phone transmitters which we could then adopt as an option for other users. In a few cases, drifter-building workshops were conducted where drifters were built by a group of teachers over the coarse of an afternoon. Teachers were provided instructions on how-to-build as well as how to track a drifter and download data in the classroom.

While the actual materials used to build the drifter have changed over time, the configuration and size of the drifter have remained consistent to the standard “CODE-style” surface drifter developed by Russ Davis decades ago (Davis et al 1982). Drogued drifters were also deployed but to a lesser extent due to the problem of getting hung-up on fixed gear. Without a costly drogue-loss detecting device, drogued drifter data is difficult to manage (Lumpkin, et al, 2012). Protocols were put in place to document deployments and recoveries over the web in order to insure consistent metadata was logged in the archive along with the actual tracks. In nearly all cases, photos were collected of the units prior to deployment.

In the case of the current meters, the instruments were first calibrated and set up to record every 10 minutes for several months. These tilt-meters which infer current based on the deflection angle of a buoyant length of PVC tethered to the lobster trap (Manning and Sheremet, 2009; Sheremet 2010) were mailed to all participants in three different field seasons (2008, 2010, and 2011). While these units did not have a compass logger, they did have a 3-d accelerometer that allows us to determine both the along-trap and cross-trap flow. In the final field season, an additional sensor was attached to the trap itself to record the angle of the trap relative to the bottom. This provided an additional stream of information that was of particular interest to the participating lobstermen.

Methods to conduct model-data comparison involved the generation of Python code in the form of a toolbox of modules to do a variety of tasks. This operation includes accessing the model output that is served via Opensource Network Data Access Protocol (OpeNDAP) using a third party “PyDAP” module or, alternatively, downloading the model output for the entire time period of the study. Both methods were used. These routines now served on a public SVN-Trac server at http://geoport.whoi.edu/whython are continually under development. The tools were used to access a variety of models from different universities but most of the development and results pertain to the UMASS-Dartmouth FVCOM model (Chen et al, 2004) output since it had the highest resolution grids throughout our study area and a variety of products to choose from. Their “forecast” product, for example, was often used to help plan deployment sites and times. Their “33 year hindcast” product which was completed about a month before the time of this writing was used to conduct comparisons.

Participants

In addition to the “key participants” listed in the title page above, there was, of course, the dozens of lobstermen who deployed the instrumentation on their traps. Individuals websites were set up to summarize the observations of each of these participants as can be seen at emolt.org under the “results” of both “temperature” and “bottom-current tilt meter”. In addition to these fishermen, there were dozens of students and teachers involved in the drifter aspect of the program. Listed in Table 1 below is the schools and institutions who helped build or deploy drifters.

Table 1. eMOLT-style drifters deployed during the period of this grant.

Institution	PI	Region	Science
WHOI	McGiilicuddy	Off Casco Bay	HABs
NEFSC	Merrick	Great South Channel	Whales
UNE	Tilburg	Downeast ME	Mussels
UNH	Goldstein/Watson	Off NH	Lobsters
Bowdoin	Laine	Casco Bay	Hypoxia
SMCC	Long	Off Casco Bay	Educational
USCG	Allen	SNE shelf	Search&Rescue
Endicott	Butler	Mass Bay	Educational
UMASS-D	Brown	Nant. Shoals	Transient Eddys
Mass-DMF	Glenn	SNE	Lobsters
RI-DEM	Angell	SNE	Lobsters
UMM	Johnson	Downest ME	GIS class project
CFCC	Shaw	Gulf Stream	Marine Tech
MPC/MBARI	Hochstaedter	Calif. shelf	Educational
ClatsopCC	Ham	Washington shelf	Educational
Mass Maritime Academy	Hyatt	Buzzards Bay	Educational
Atl.Salmon Fed.	Whoriskey	St. Lawrence Estu.	Salmon
NOAA-Orono	Kocik	Gulf of Maine	Salmon
Redwoods CC	Grantham	Calif. shelf	Educational
Center Student Coastal Research	Buckley	Mass Bay	Nutrients
OceanQuest	Mullin	Vineyard Sound	Educational
Dauphin Island Sea Lab	Graham	Gulf of Mexico	Oil spill response
USF	Weisberg	Gulf of Mexico	Oil spill response
AOML	Johns	Gulf of Mexico	Oil spill response

BCC	Rak	Narragansett Bay	LNG siting
GLERL	McCormick	Lake Erie	Model validation
FSU	White	Gulf of Mexico	Oil spill response
UMASS-B	Hager	Boston Harbor	Educational
Quincy High	Johnson	Boston Harbor	Educational
New Bedford Tech	Reynolds	Vineyard Sound	Educational
Pope John HS	Reynolds	Vineyard Sound	Educational
Science and Discovery HS	Reynolds	Vineyard Sound	Educational
South Shore Vo-Tech	Reynolds	Vineyard Sound	Educational
Children School of Science	Reynolds	Vineyard Sound	Educational
Bourne Community Boating	Reynolds	Vineyard Sound	Educational
URI/GSO	Kincaid	Blockl Island Sound	Coastal Currents
Penn State	Boughton	Lake Erie	Educational
Maine Maritime Acad	Sahl	Pen Bay	Tidal Power
Canterbury Sch Marine Studies	Cummings	Gulf of Mexico	Educational
Sea Education	Zetler	SNE	Plastic drift
UMichigan	Schwab	Lake Michican	Model validation
Adv. Biotech Institute	Reynolds	Vineyard Sound	Educational
Cape Henlopen HS/UDEL	Geppert/Luther	MAB	Educational
NATECH	Schroer	Laborador shelf	Waster water
NOAA Adopt-a-Drifter	Stanitski	Stellwagen Bank	Drogue comparison
Roger Williams U.	Rutherford	Narragansett Bay	Alternative transmitters

Data

The eMOLT temperature, drifter, and now moored current meter data is posted at emolt.org and accessible via OPeNDAP as it has been for the last decade. Computer code is now posted on the website that allow users to by-pass the traditional point-and-click web-based methods so that they can access the data directly in from PYTHON or MATLAB environments. During the period of this grant more than 1.5 million bottom temperature and 250 thousand drifter fixes were recorded and archived.

Results and conclusions

Before relating specific details, we can say that nearly all aspects of the proposed work were completed and in some cases far more work was conducted than expected. Over the course of the grant period the number of drifters swelled to approximately one hundred per year and dozens of bottom current meters were deployed . A few aspects of the study on the other hand, were not carried out exactly as planned. As explained in more detailed sections below, the salinity sensors (funded in eMOLT II) collected more data during the grant period but were not actually deployed by lobstermen. Also, very little surface current comparisons were made with HF-radar but this difficulty had more to do with the lack of HF-radar in the Gulf of Maine region. Finally, while considerable modifications were made to the eMOLT websites to display the information, the pages are not still not professional presentations.

The details of various aspects of the project now follow. We begin with a summary of the observations and conclude with the results of the model validations.

Drifter observations

As listed in Table 1 in the “Participants” section above, it is obvious the drifter project has expanded beyond the plans associated with this grant. Purely by word-of-mouth, the drifters we first developed as part of eMOLT PhaseIV have been useful in a variety of studies. Given the NEC-funding specific in this grant, we were able to further develop the design of the drifter and get dozens deployed off our coast. For example, lobstermen were funded to help deploy units off the coast of Cohasset MA. A few more fishermen were funded to recover drifters. Those deployed in the Vineyard Sound, for example, often came ashore on the Elizabethan Islands not accessible by car. Fishermen who helped recover drifters often became interested in the project and assisted in subsequent deployments and recoveries.

In order to generate the following figures our website was used where it is now possible to select “by-year” in order to visualize tracks on a googleMap display. It can be seen in 2009 (UL) and 2010 (LL), for example, that many tracks were generated south of Buzzards Bay. These were associated with a project funded by the Southern New England Cooperative Research Initiative to study lobster larvae advection led primarily by Mass DMF investigators. A better way to visualize the drifter tracks is via animations. These googlemaps and animations can now be viewed by visiting the main drifter site at:
http://www.nefsc.noaa.gov/drifter/
and then clicking on the third link. This will take you to a drop-down menu called “visualizations”. If the user then clicks the “Home” tab, there is the option of tracks by investigator.

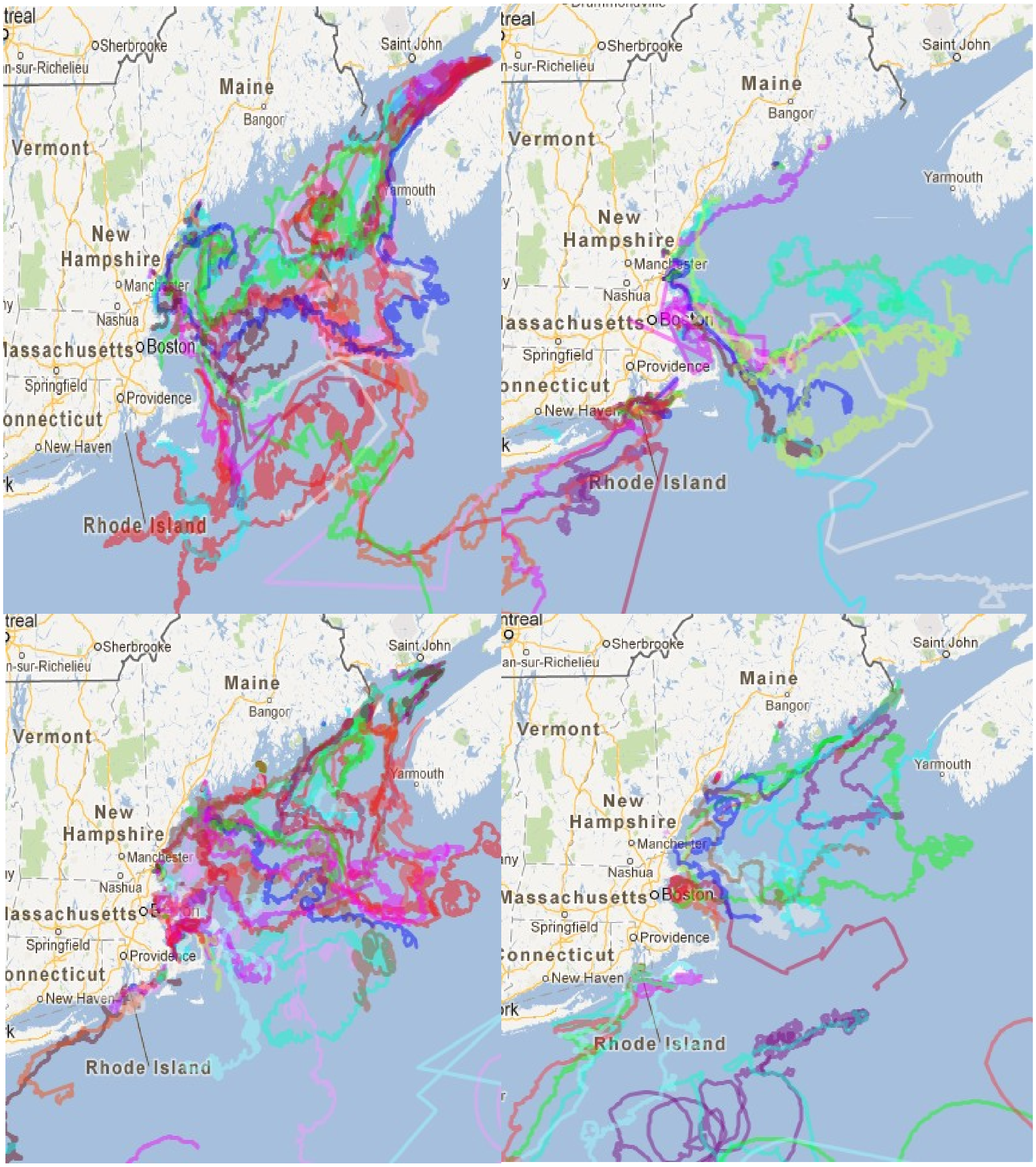


Figure 1. Drifters tracks from 2008 (UL), 2009 (UR), 2010 (LL), and 2011 (LR) as generated by the drifter googlemap site.

A drifter-building workshop was held in August 2011 in Monterey California. Leveraging NSF-funding to the "Marine Advanced Technology Education" group, several colleges were able to send marine science teachers to this 3-day event and allow them to return with a ready-to-deploy drifter. The drifter construction manual we have developed over the last few years was followed and teachers were able to have their students build more drifters. The primary focus here, however, is not to maximize the drifters deployed but to get the most out of the drifter data that is generated. Much of the teaching is associated with the downloading, processing, and visualizing of drifter tracks. Students learn how to plot the tracks and overlay other information such as the wind fields and the numerical model fields. The tracks are now visible on the MARACOOS "asset map" where users can overlay other observed and modeled variables.

Another drifter-building workshop was conducted in Woods Hole in May 2012 where several K-12 teachers (Figure 2) were able to construct four surface drifters. These units were deployed later that month on the Northeast shelf alongside tagged turtles and three are still transmitting in Oct 2012 from beyond the Grand Banks.

These tracks of these drifters along with the turtles are followed by school children this fall at http://www.nefsc.noaa.gov/drifter/drift_tas_2012_1.html

Figure 2. NOAA Teacher-at-Sea Program alumni after a drifter-building session in Woods Hole in May 2012 (Photo by Shelly Dawicki).

Bottom current meters

The bottom current meter project has succeeded beyond expectation. After our initial pilot deployment on 11 lobster traps for a few months in the fall of 2008, another set of 27 were deployed and recovered in fall of 2010. Given these encouraging pilot projects, we then sent units to 50 different lobstermen in 2011 (Fig). These were out for the entire fishing season. While we have not got all of them back at the time of this writing, but most have returned good data. The results are posted under the “results” page emolt.org website as “Bottom Current Tilt-meter Study”. Various plots are posted for each participant including some zoomed in on interesting episodes that were recorded. The locations are depicted in Figure 3 are those for the 2011 deployment. An example of the type of data returned is plotted in Figure 4. It is understood, that in these example plots, the two dimensions represent an along-trap and cross-trap direction, which depending on when the trap was hauled, will change during the time series. It is not a true representation of the directional flow field but it provides a message of the flow speeds and their variability.

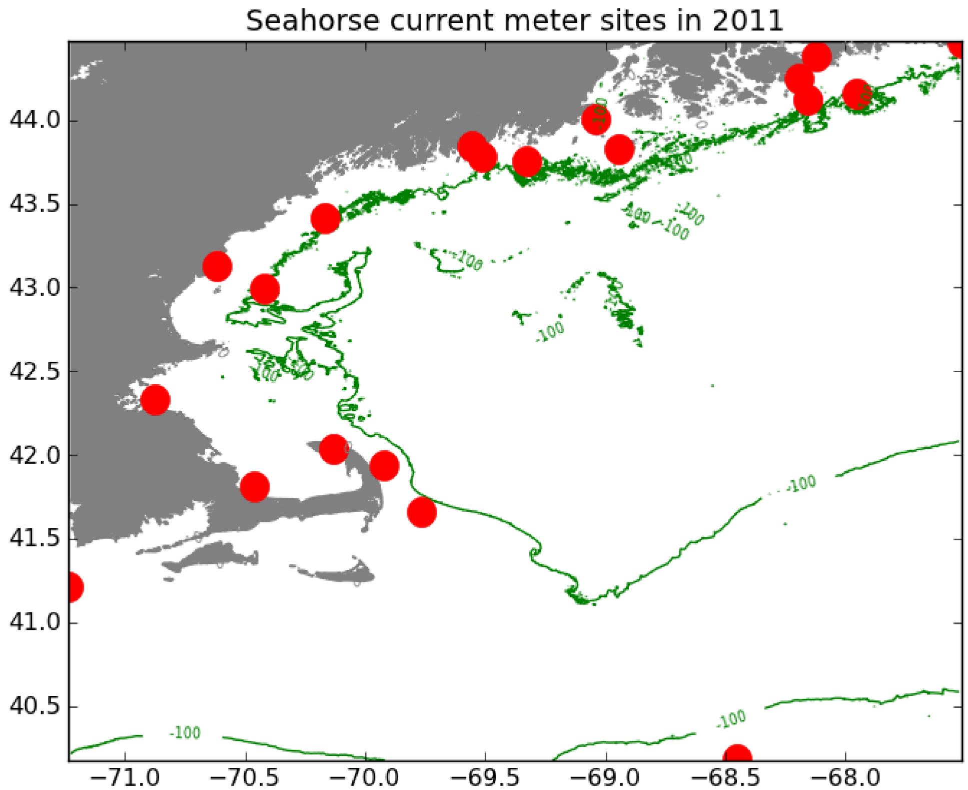


Figure 3. Locations of good tilt-meter data from 2011 deployment. The 100m isobath is shown in green.

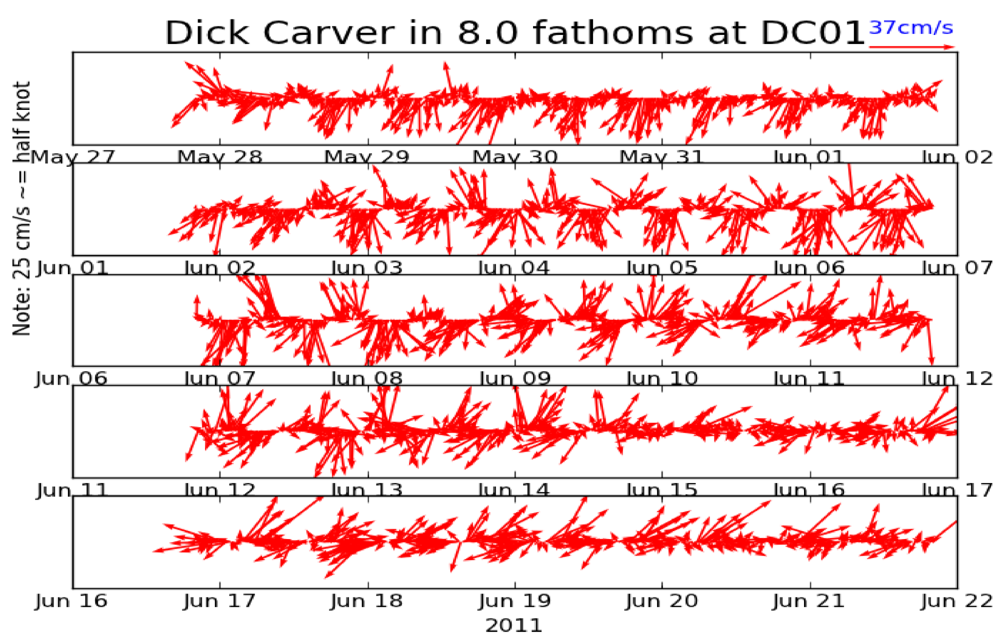


Figure 4. Example stickplot of one lobstermen's bottom current observations from 8 fathoms (~15m) off mid-coast Maine.

Salinity observations

As noted previously, the Microcat salinity probes deployed by lobstermen in eMOLT Phase II, were redeployed in 2012 in studies of Cohasset Harbor and Waquoit Bay. The objective in both cases was to investigate the flushing of the harbor systems and compare the salinity variability in different sections of the estuary. As seen below in Figure 5-7 for the case of Cohasset Harbor, a great deal of variability was recorded due to the local river and tidal processes. The motivation behind this study came from problems lobstermen were having in holding their catch in the local carts. They had noticed a change in the harbor ecosystem. They wondered about the effects of upstream effluents as well as the town's diversion of some water through culverts.

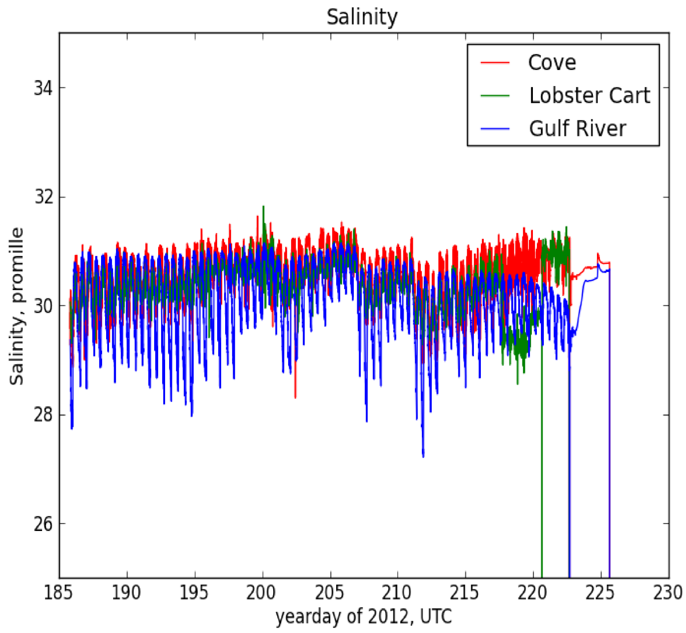


Figure 5. Salinity observations July 5th through August 11th, 2012, at three locations in Cohasset Harbor.

As noted in a story in the local press at http://www.patriotledger.com/archive/x482009742/Cohasset-student-scientists-hit-the-water-to-learn-about-marine-research, bottom-current meters and drifters were also used in the analysis of this system.

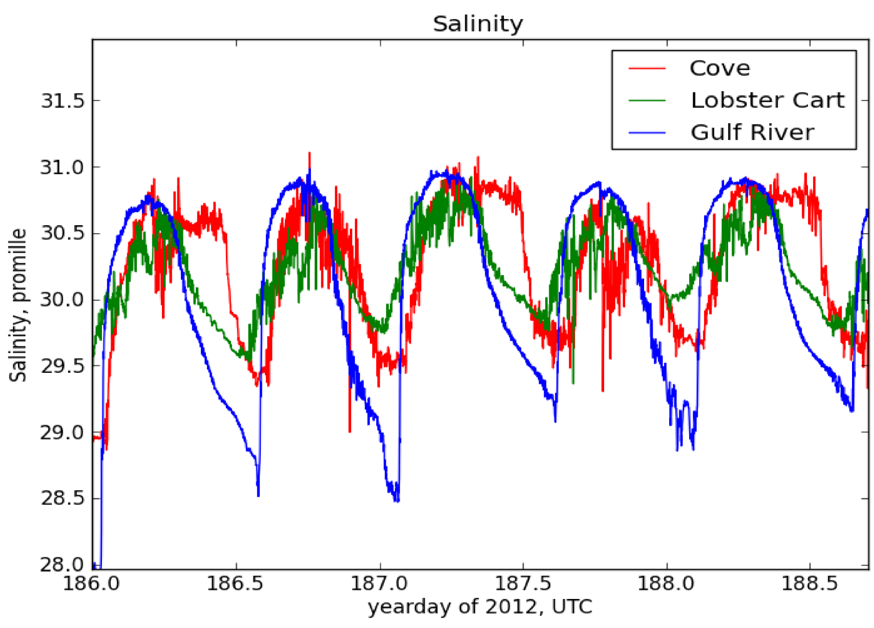


Figure 6. Same as Figure 5 zoomed in 6-7 July 2012.

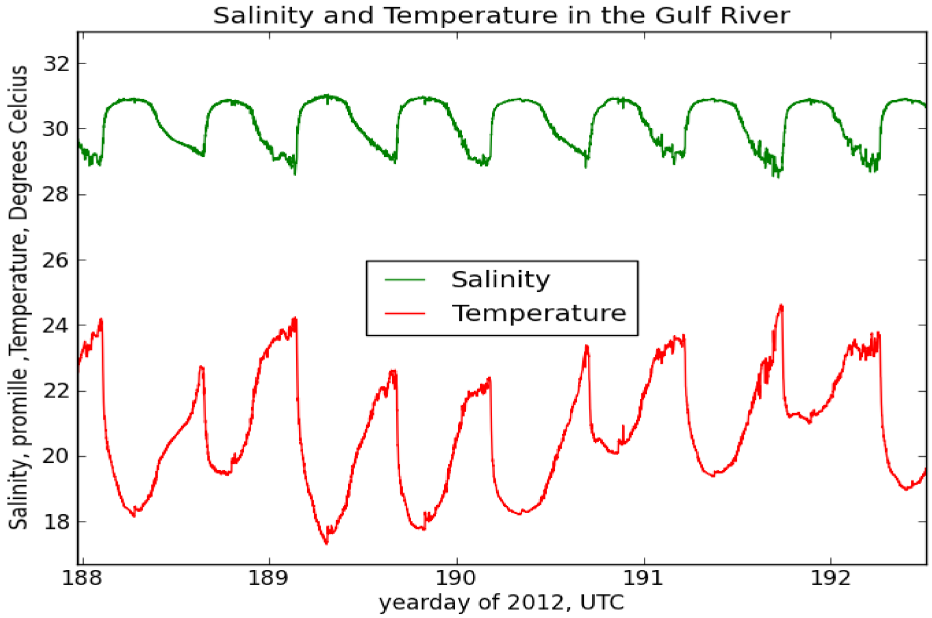


Figure 7. Salinity and temperature as measured at Gulf River site 8-12 July 2012.

The Waquoit Bay salinity study is still underway and results of that investigation will be forth coming. A progress report by Sheremet to a Navy funded project is available at http://*www.onr.navy.mil/reports/FY10/posherem.pdf.*

Digital cameras

Finally, the most recent eMOLT-related work in is in deploying digital-cameras on lobster traps. Working in collaboration with ocean engineers at Woods Hole Oceanographic Institute, we prepared several cameras and sent them out to lobstermen. With the help of NOAA divers, we had tested their waterproofed housings and the light limitations in water depths up to 10 meters off the dock and were happy to find they also work in the various environments that the fishermen work. While these cameras originally were planned to help us document the performance of our instrumentation (drogued drifters and tilt current meters), the 20+ plus lobstermen who responded to our email are obviously interested in monitoring the activity of their trap so that a new collaborative project is underway. Since the GoPro cameras have battery power limited to 4 hours when a frame is stored each minute, our next step is to find a camera system with true time-lapse functionality so we may get time series over days or weeks. During the Winter of 2012/2013, we will be experimenting with a “GoPro controller” computer chip that is expected to increase the battery life to approximately 30 hours. In the meantime, several lobstermen have tried the camera and have contributed their images visible at http://www.flickr.com/photos/emoltlobcam. Lobstermen and scientist alike may obtain a better understanding of the catch dynamics. A example photo obtained is provided below.

Figure 8. Example of lobster photo as archived by lobstermen. This one is by Bill Doherty in 10 fathoms outside Boston Harbor.

Model validation

Given the Massachusetts Ocean Partnership (MOP) funding the FVCOM modeling group, a complete hindcast of our coastal waters from 1978 to present is complete. Simulations of the entire Gulf of Maine circulation at 40+ depths are available for each hour and are currently posted for anyone to examine at:

http://porpoise1.smast.umassd.edu:8080/fvcomwms/

This model output will be particularly valuable to fisheries biologist, for example, who are trying to understand the interannual variations in recruitment of commercially-important ground fish on Georges Bank and elsewhere. We can now provide them with the potential transport paths of eggs and larvae for different years. In Figure 9, for example, we show the different trajectory of particles released at the same location on October 15th in different years. We conduct other experiments to examine the flow at different depths as illustrated in Figure 10.

In the past year, we have started comparing the model particle trajectories with actual drifter tracks. We have used the archived drifter data from as late as the 1980's and calculated, for example, the “separation distance” between model and observed restarting the comparisons every two days. The result for a particular drifter (Figure 11) show the affect of the model's tidal excursions that were not resolved in the rough drifter fixes. This same comparison has been conducted for dozens of drifters which has generated a large dataset as shown in Figure 12 below. The results vary from a few kilometers to tens of kilometers per day. A particular example is shown in Figure 13.

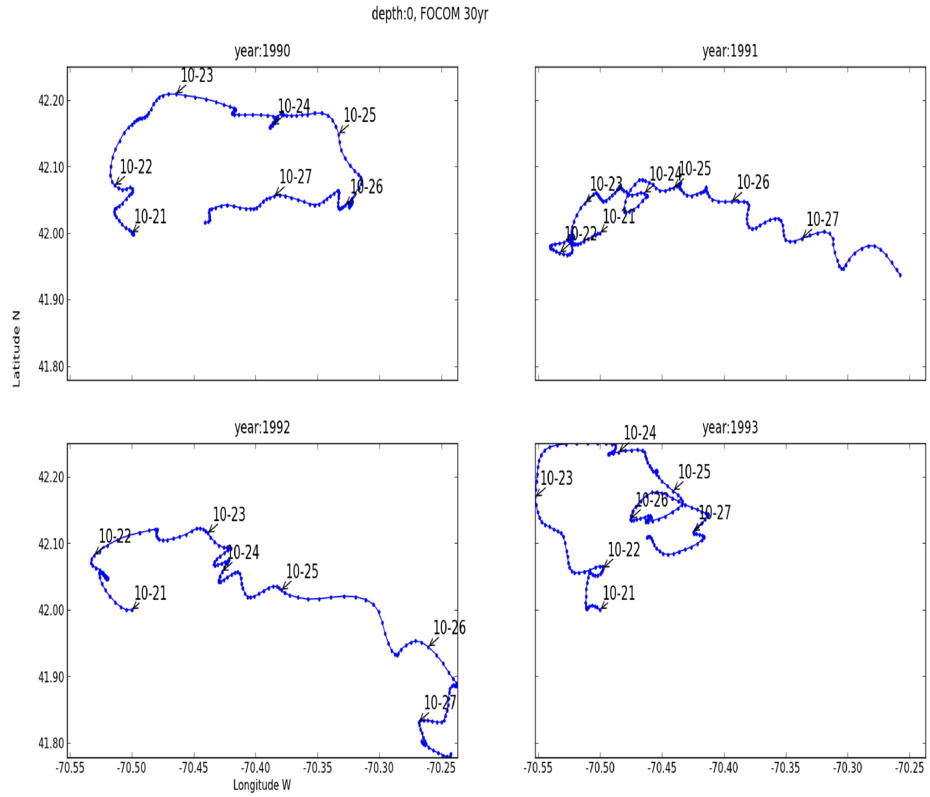


Figure 9. Model trajectories and daily positions (red dots) of numerical drifters deployed at the same location in different years.

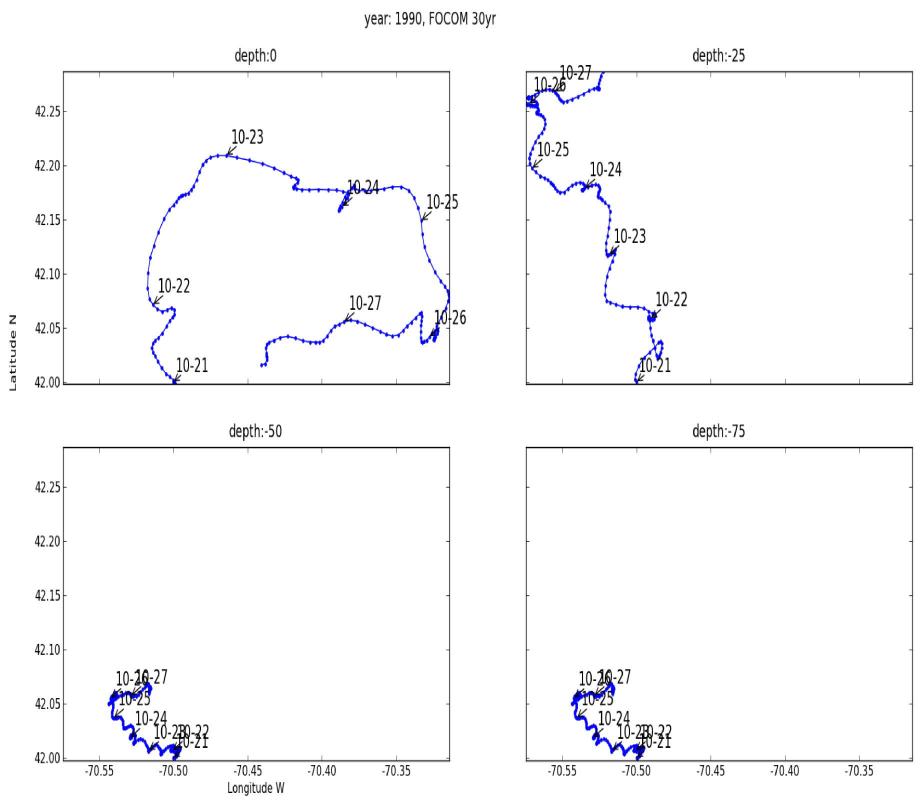


Figure 10. Model trajectories beginning at the same time but at different depths.

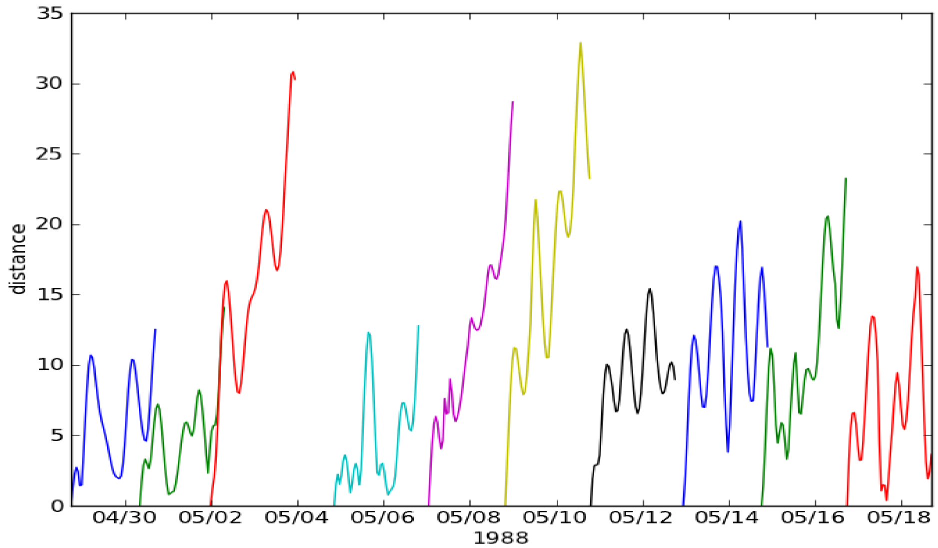


Figure 11. Separation distance of modeled vs observed drifter.

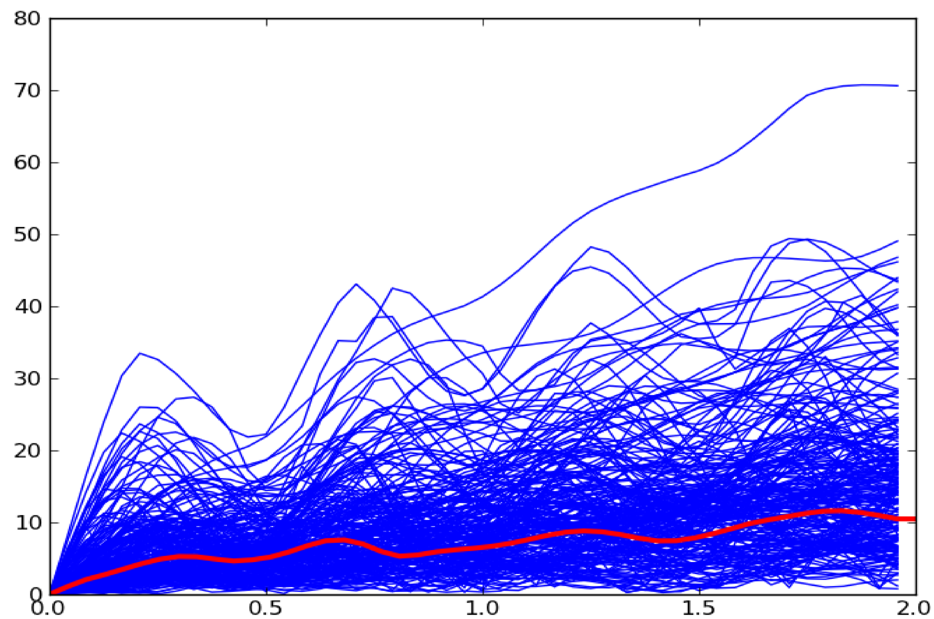


Figure 12. Model vs oserved drifter separation in kilometers (y-axis) vs time in days (x-axis) for late 1980's hindcasts.

A considerable amount of work was devoted to validating models. Leveraging some work conducted with the Northeast Coastal Ocean Forecast System

(NECOFS) group at UMASS Dartmouth, we have compared dozens of moored and drifter observation of current with their model output. As documented at:

http://www.nefsc.noaa.gov/epd/ocean/MainPage/circ/necofs_vs_eMOLT.html

While the comparisons listed there are obviously very cursory and not well quantified, efforts are now underway to generate better metrics on how well the model, in general, is simulating flow fields, temperature, and salinity. This will be on on-going effort for years to come as the model output continues to improve

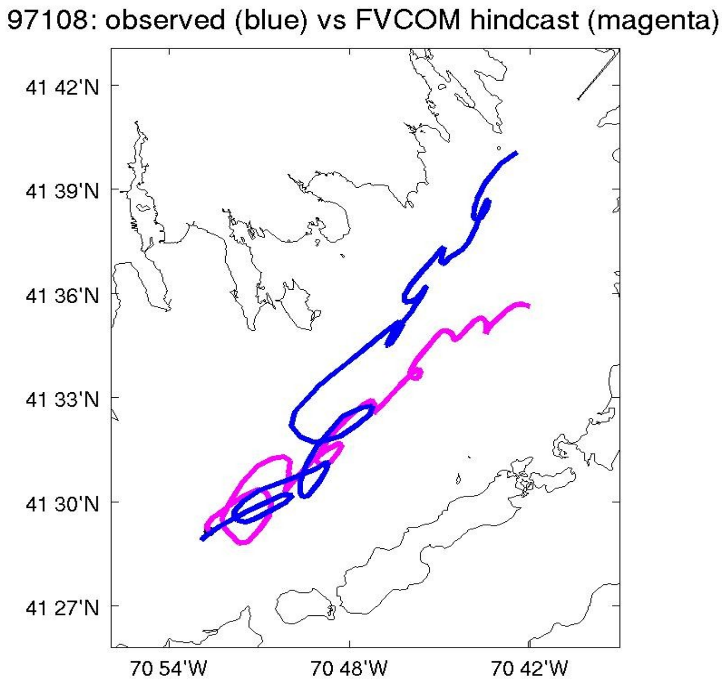


Figure 13. Example of comparing model drifter track vs observed. This case is for one drifter flowing up Buzzards Bay in July 2009 where the model captures the events but not the absolute values.

and more and more data is assimilated into the model runs. The most important outcome of the eMOLT project, in general, is the fact that eMOLT bottom temperatures are now being used to tune the model. While many coastal model hindcast assimilate seasurface temperatures from satellite, this group also has been able to assimilate our NEC-funded hourly-values of bottom temperatures to better define the vertical thermal structure.

As noted, part of the effort is to generate “metrics” on how well the models perform. We began by comparing observed vs modeled drifter tracks calculating a “separation distance per day” but found that metric not suited to many ares of our coastal ocean where there are strong frontal zones. Two planktonic particles can not expect to follow the same route as they separate more than a kilometer or more. In other words, as our observed drifter path departs from its modelled component, it quickly resides in a different water mass and is directed but a different force. As a consequence we have subsequently worked on a new, more realistic metric by comparing the drifters measured velocity with the model's velocity on a point-by-point basis along the observed drifters path. We have found this to be a more suitable measure of the model's performance (Fig. 14).

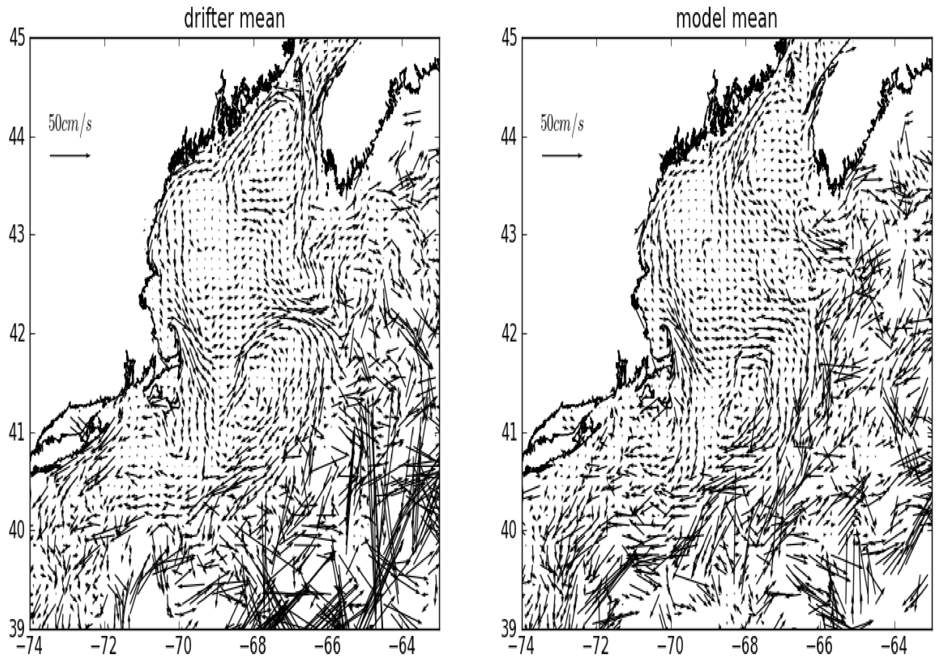


Figure 14. Comparing drifter-derived subtidal flow in 0.1 deg bins with FVCOM derived flows.

The most important progress has been in converting our code from MATLAB to the open source PYTHON. This has allowed us to install the routines on multiple machines and to share the code with others. We have initiated a Woods Hole Python Users Group that meets on a weekly basis to discuss this transition and to share ideas on how to conduct it. It has resulted in a repository of code posted at: http://geoport.whoi.edu/whython We have made these modules now available to the public so that anyone can conduct our model-data comparisons. Given that they utilize a non-commercial software, these utilities could be downloaded and used by teachers and students, for example, who may not have the resources for MATLAB and other commercial software.

Now that the tools have been developed (primarily PYTHON routines), we have begun to conduct more quantitative analysis of the models performance. We often examine the model output from “hindcast” runs. These are simulations of past periods. It is essential to test the model's hindcast performance prior to its forecast performance as these simulations have the advantage of “data assimilation”. If a model can not provide reliable hindcast, it can not be expected to provide a reliable forecast.

Considerable advances have been made towards the validation of local ocean models in the last few years. Given new utilities that allow investigators to remotely access a variety of web-served model output, it is now possible to examine these models without needing to bother the modeling teams that generate the output. These are powerful new tools that can be leveraged.

Because of the activity associated with this NEC-funded grant, Manning was invited to sit on a advisory panel that evaluates UMASSS Dartmouth's FVCOM model operations: the Northeast Coastal Ocean Forecast System. Much of the work that has been done and the tools that have been develop in this grant therefore have addressed the FVCOM model in particular. However, there are multiple models that simulate our coastal waters and these tools have been applied to these other models as well.

The validation of models has progressed along a few fronts associated with different data products. We compare the model output to eMOLT bottom temperatures, NERAOOS moored current observations, and eMOLT drifters as shown below in Figures 15-17. While the website noted above is a work in progress and should NOT be linked from any public site, it provides an up-to-date summary of our efforts to date. As of this writing, most of the code has been written to make the comparisons but a quantitative analysis of the models will be complete in a few months from now and the results should appear in a journal publication.

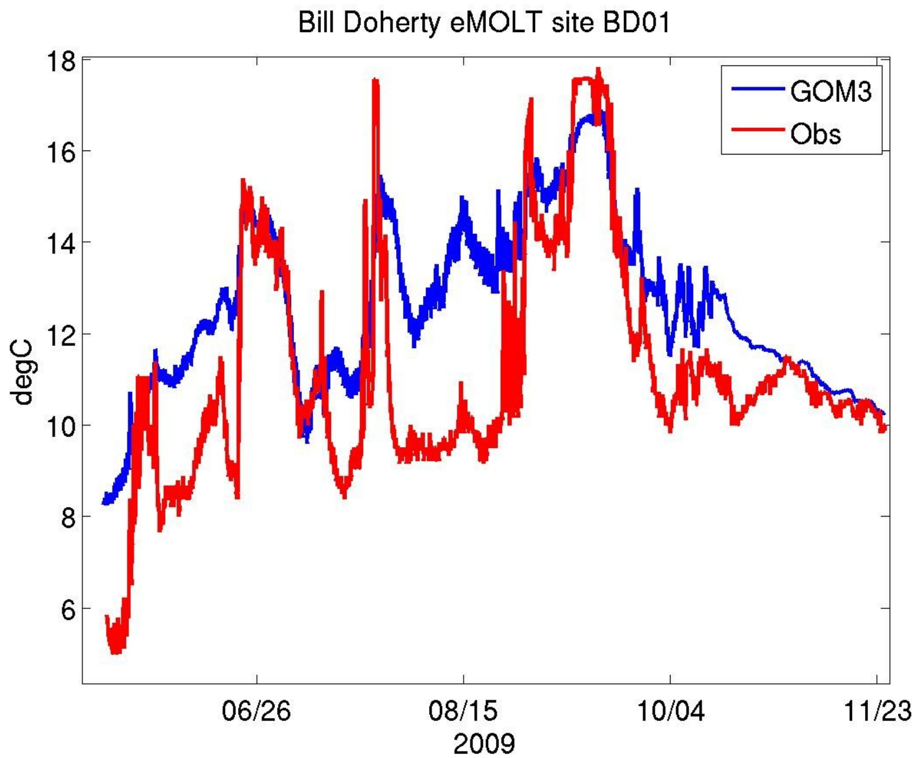
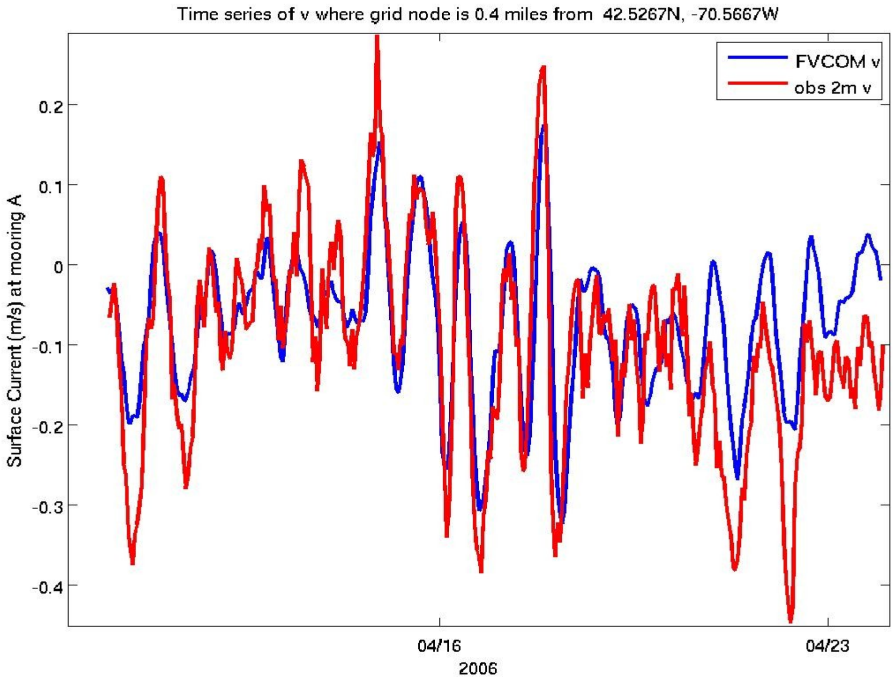


Figure 15. Example of comparing model temperatures to eMOLT bottom temperatures. This case is for Bill Doherty's site off Boston Harbor in 20 meters of water.



Figure

Figure 16. Example of comparing model to NERACOOS mooring time series of northward velocity. This case is for mooring "A" in April 2006 where the model does generally well.

Our drifter data is accessed by other groups for the purposes of validating their models. Other labs (North Carolina State, UMASS Dartmouth, and Rutgers University) have manuscripts underway that describe a model – data comparison using eMOLT data. One of the figures from NCSU study is provided in Figure 17.

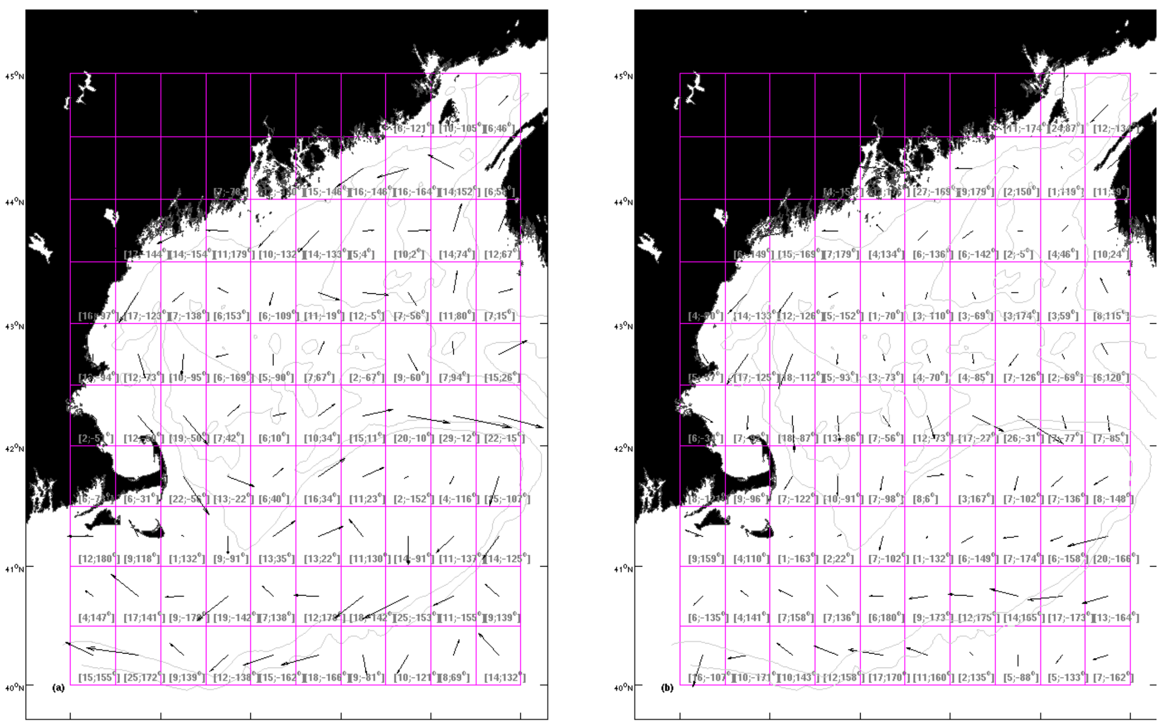


Figure 17. From Li, He, and Manning 2013 comparing model vs data mean flow field in 0.25 deg bins

Partnerships

As noted in recent annual reports, given some of the drifters funded through this Phase VII project, we have been able to build a close collaboration with multiple institutions. The Zephyr Marine Education Foundation (Rob Reynolds) in Woods Hole, for example, began in April 2011 and throughout that summer, conducted bi-weekly drifter deployments. Working in local waters, groups of primarily high school students go on-board, witness the deployments, and subsequently follow the path of the drifters on a customized googlemap on-line. From this project alone, approximately 70000 kilometers of ocean has been logged in Southern New England Waters and beyond. As these drifters approach other shores, they are picked up by students elsewhere. URI students, for example, have been involved with a few recoveries and have made some deployments themselves. A total of 14 drifters were deployed by URI students in 2011 and some of them transmitted well beyond the tail of the Grand Banks.

Projects like these are spawning other projects with other schools and organizations. As noted in the “presentations” section below, we have connected with multiple educational organizations both locally and nationally and are currently in the process of proposing a nation-wide drifter project.

Impacts and Implications

Hundreds of eMOLT-style drifters have been deployed over the last several years in support of the ECOHAB and GOMTOX programs to study the advection of Harmful Algal Blooms. In 2010 for example, the GOMTOX-funded drifters revealed an unusual offshore veering of the coastal current near Casco Bay that helped explain the lack of toxic cells in the Mass Bay region that year. The realtime plots of these drifters are often watched by shellfish managers as a index of the surface water transport towards or away from their shores. In years like 2005 where there was a series of northeasterly wind events, the drifters could be seen along the coast and advecting shoreward. It was a very different situation in 2010 (Figure 18). A manuscript recently submitted (McGillicuddy et al, 2011) provides the full story of the suppression of HABs in 2010. Another manuscript describes a drifter's path after being deployed in a documented case of discolored water off New Hampshire where toxic dinoflagellate *Alexandrium fundyense* were in excess of 1 million cells per liter (McGillicuddy et al, 2013).

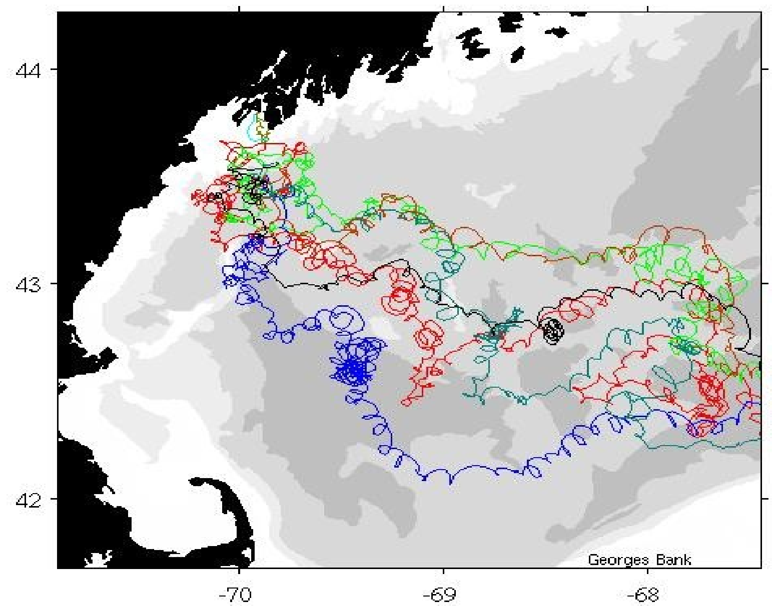


Figure 18 GOMTOX-funded drifters in 2010 tracking offshore from Casco Bay and therefore explaining the lack of toxic cells appearing in MassBay shellfish beds.

There are many other recent examples of why these models are useful. Last year, there was the question of why a sudden rise in the toxic Alexandrium cells in Nauset Inlet occurred in June 2009. We were ask to evaluate the circulation pattern of the coastal current just prior to that event to determine if there was an influx of surface waters into the inlet. The combination of modeled and observed paths (Figure 19) depicts the real possibility.

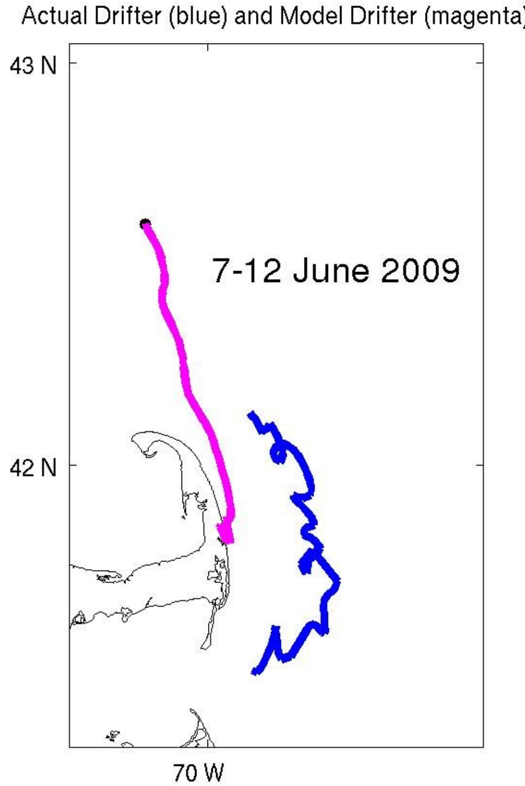


Figure 19. Trajectory of both actual and simulated drifter paths prior to the June 2009 toxic Alexandria outbreak in Nauset Inlet depicting the numerical results of a particle released in the model fields just east of Stellwagen Bank on June 7 (magenta).

In March 2012, we were asked by some marine mammal researchers to estimate the track of a dead right whale. We plugged in the positions and times of the last-known sighting and simulated the trajectory using both UMAINE POM model as well as the UMASS FVCOM model to provide them with the plots posted along with other such examples at:
http://www.nefsc.noaa.gov/epd/ocean/MainPage/whale/whale.html

We were asked by UNH investigators who were studying larval clam development to predict the path of a surface particle released off shore of Cape Elizabeth Maine. In order to have them visualize both the mean and the variability of that predicted trajectory, we released particles every few days in the model fields associated with April 1988 and generated the figure below. Our objective was to demonstrate the degree of variability in a particles fate when released at different times. While one particle could be driven into Casco Bay another released a few days later could end up off the New Hampshire coast (Figure 20).

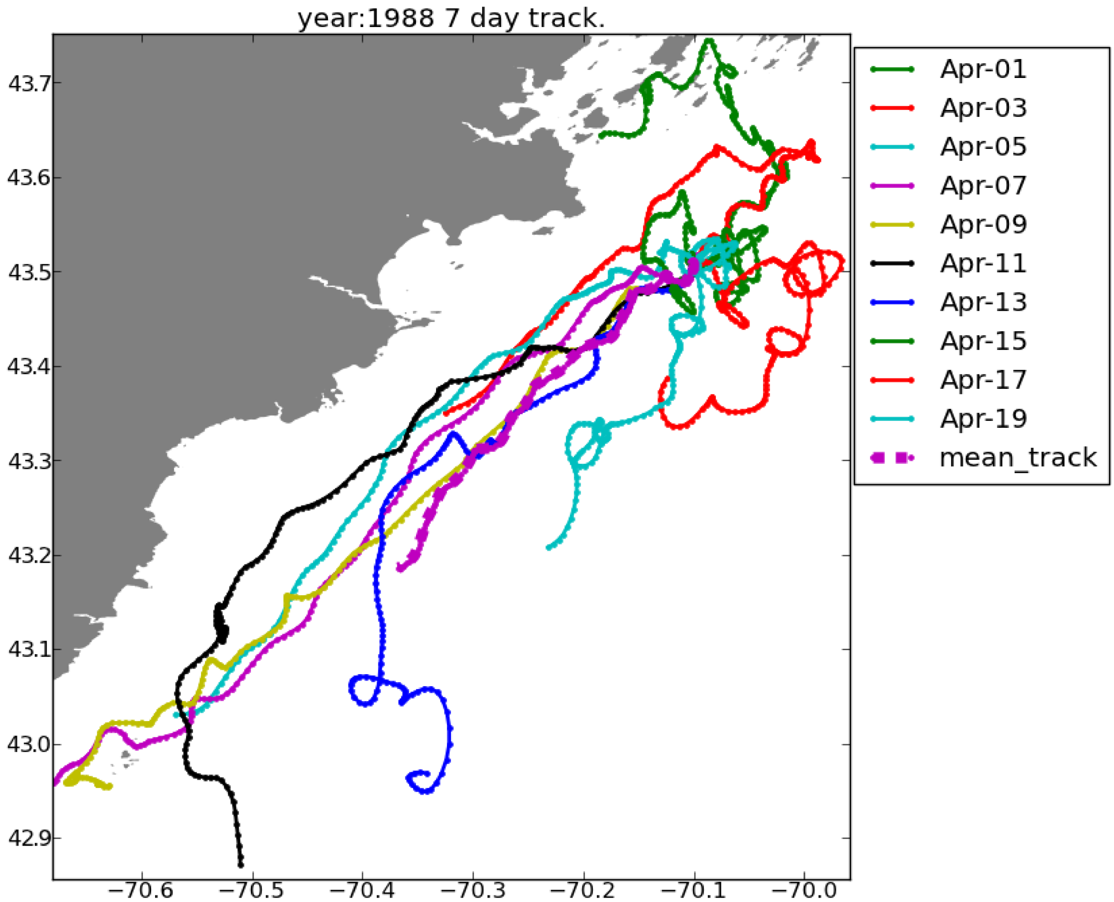


Figure 20. Example of the variability in particle tracks through the model fields when particles are released at different times.

One of the most interesting studies using eMOLT data was instigated by the fishermen who collected the data. In the Fall of 2011, a few fishermen called the science party to ask about the abnormal conditions they were observing on the Southern New England Shelf. Fortunately, their eMOLT temperature probes and a drifter built by community college students captured the event which was subsequently written up on the nature.com scientific reports (Gawarkewitz, et al 2012). Never before has Gulf Stream water been observed on the shelf in this region.

At the time of this writing in Oct 2012, a series of unrelated stories have been released in the news concerning our project. Links to each of these stories are provided at:
http://www.nefsc.noaa.gov/epd/ocean/MainPage/drift/inthenews.html

Related Projects

The most relevant projects are the Regional Associations of Coastal Observing Systems in both the Mid-Atlantic (MARACOOS) and the Northeast (NERACOOS). As a member of the board of directors on the former and the data management committee on the latter, Manning is actively involved with these initiatives and hopes to promote the eMOLT idea in both organizations and elsewhere around the country. Two white papers were submitted to the IOOS submit to be held in Nov 2012.

The Gulf of Maine Toxicity (GOMTOX) project is also very much aligned with eMOLT objectives in the observation and modeling of ecosystem processes over multiple years. The objectives of the Northeast Coastal Ocean Forecast System (NECOFS) also runs parallel to eMOLT directions. We are beginning to exchange ideas with the Northeast Cooperative Research Program in the last few months where, for example, we are attempting to develop a real-time probe for both mobile and fixed-gear applications. The objective is to exchange data, ideas, code, and instrumentation between all of these analogous efforts.

Other organizations we have connected with in the last few years include:

- COSEE NOW and OS
- Marine Advanced Technology Education
- Stellwagen National Marine Sanctuary
- New England Ocean Science Education Collaborative
- NOAA's Adopt-a-drifter
- NOAA's Teacher-at-Sea
- Educational Passages
- National and Mass Marine Educators Associations
- Zephyr Education Foundation and OceanQuest
- Sea Education Association
- Woods Hole Science and Technology Education Partnership
- Fishermen Scientist Research Society
- Gulf of Maine Research Institute
- Gulf of Maine Institute

Presentations

A presentation on drifter tracks was delivered at a meeting of Atlantic Salmon researchers in Portland Maine in January 2011. They are interested in the pathways of smolt transport after they enter the ocean from the rivers in Maine. As documented in Friedland et al (2011), the variability of the coastal current and its potential to change over climatic time scales may significantly affect the ability of salmon to maintain there existing population levels.

A presentation was made to the public at the South Shore Art Center in Feb 2011 where there was a show on "things in motion". The animated drifter tracks provided an interesting discussion among those that attended.

A full day eMOLT session at the Maine Fishermen Forum occurred on 3 March 2011. Dozens of lobstermen attended this event and were treated to a series of talks including those by Ru Morrison (head of the Northeast Regional Association of Coastal Observing Systems), Diane Cowan (Lobster Conservancy), Lew Inzce (formerly USM lobster biologist now at NSF), Paul Music (NOAA), and Heather Desse (Island Institute). Lobstermen heard first hand of the efforts underway to provide them with a real-time ocean forecast system as well as the results of the various eMOLT projects by Manning and Sheremet. This session was well attended (Figure 21) and exposed many more fishermen to our efforts to monitor and understand the environment. Another presentation was made by Manning at the March 2012 forum and one is currently being planned for March 2013.

Figure 21. Active eMOLT participants at the March 2011 10-year anniversary get together.

A presentation was made to colleagues at the Massachusetts Division of Marine Fisheries in June 2011 illustrating the mean flow patterns that are beginning to emerge from the multiple drifter deployments this group has assisted with in the last few years. This study was well documented in the final report by Glenn et al 2011.

A presentation was made to the Boston Sewage Outfall Scientific Advisory Committee in June 2011 showing the results of drifter and model tracks in Mass Bay.

A presentation was made at the National Marine Educators Annual Conference in Boston, MA on 1 July 2011. The objective is to transfer the drifter technology to teachers around the country. We shared the construction manuals, computer code, and lesson plans needed to engage students in both the hands-on activity of building and tracking of drifters.

Elliot Thomas, a long time eMOLT participant, gave a eMOLT presentation to fellow lobstermen at the Annual Fishermen Scientist Research Society Meeting in Truro, Nova Scotia since none of the science party could make the meeting. His presentation was well very received so we hope to have more fishermen present results in the future.

Presentations on eMOLT were also made to the:

- ICES Working Group on North Atlantic Regional Seas in March 2012
- Earth Day Celebration at the New England Aquarium in April 2012
- NOAA's Teacher-at-Sea Alumni workshop in May 2012
- American Fisheries Society Meeting in New Bedford in June 2012
- Boston Harbor Educators Conference at UMASS-Boston in Sep 2012
- Massasoit Community Colleges's earth science class in Oct 2012
- Newton North High School group also in October 2012

Finally, a presentation is planned at the New England Ocean Science Education Collaborative Ocean Literacy Summit in Narragansett, RI in Nov 2012.

Student Participation

It is difficult to estimate the number of students who have been exposed to the eMOLT drifter project but it is likely in the thousands. While an example photo is provided below (Figure 22), there is a whole gallery of similar photos posted at: http://gisweb.wh.whoi.edu/ioos/drift/photos.html

Figure 22 . Fall River, MA Elementary School students after signing their names to the drifter to be deployed in Narragansett Bay (Photo by Bob Rak, BCC)

Published reports and references

Aretxabaleta, A., D. McGillicuddy, K.W. Smith, J.P. Manning, and D. Lynch, 2009. Model simulations of the Bay of Fundy Gyre: 2. Hidcasts for 2005-2007 reveal interannual variability in retentiveness. Jour. Geophys. Res. Vol. 14, C09005, doi: 10,1029/2008 JC004948, 2009.

Davis., R. 1985. Drifter Observations of Coastal Surface Currents During CODE: The Method and Descriptive View. J.Geophys.Res.,90,4756-72.

Friedland, K.F., J. Manning, J. Link, A. Gilbert, and A. O'Connell. 2011. Variation in wind and piscivorous predator fields affecting the survival of Atlantic salmon, Salmo salar L., in the Gulf of Maine. Accepted by Fishereis Management and Ecology.

Gawarkiewicz,G., R. Todd, A.J. Plueddmann, M. Andres, J.P. Manning, 2012. Direct interaction of the Gulf Stream and the shelfbreak south of New England. Scientific Reports 2, doi:10.1038/srep00553

Glenn, R., K. Whitmore, T. Pugh, M. Gibson, T. Angell, R. Wahle, J. Manning, L. Dellinger, A. DeCosta, and S. Wilcox. Examining settlement dynamics of postlarval American lobster, (Homarus americanus), in Lobster Management Area 2. Final Report to Southern New England Collaborative Research Initiative and available at: http://www.cfrfoundation.org/wp-content/uploads/2012/04/Lobster-Settlement-Final-Report-w-appendices.pdf

Li,Y., R.He, J. P. Manning. The Coastal Connectivity in the Gulf of Maine in Spring and summer of 2004-2009. 2012 submitted to DSRII.

Lumpkin, R., S.A. Grodsky, L. Centurioni, M-H Rio, J.A. Carton, D. Lee, 2012. Removing spurious low-frequency variability in drifter velocities Submitted to JTECH.

McGillicuddy, D.J., Jr., D.W. Townsend, R. He, B.A. Keafer, J.L. Kleindinst, Y. Li, J.P. Manning, D.G. Mountain, M.A. Thomas, D.M. Anderson. 2011. Suppression of the 2010 Alexandrium fundyense bloom by changes in physical, biological, and chemical properties of the Gulf of Maine. Submitted to Continental Shelf Research.

McGillicuddy, D.J., M.L. Brosnahan, D.A. Couture, R. He, B.A. Keafer, J.P. Manning, C. Pilskaln, D.W. Townsend, and D.M. Anderson. 2013. A red tide of *Alexandrium fundyense* in the Gulf of Maine. In prep for DSRII.

Manning, J.P. and E. Pelletier, 2009. Environmental Monitors on Lobster Traps (eMOLT): long-term observations of New Englands's bottom-water temperatures, Journal of Operational Oceanography. Vol 2-1, p.25-33.

Manning, J.P., D. McGillicuddy, N. Pettigrew, J. Churchill, L. Incze, 2009, Drifter Observations of Gulf of Maine Coastal Current, Continental Shelf Research. doi:10.1016/j.csr.2008.12.008.

Manning J. and V. Sheremet, Low-cost bottom-current meter: results from prototype deployments. 2009. Coastal Environmental Sensor Network Conference 23-24 July 2009. UMASS Boston

Sheremet, V.A. 2010: SeaHorse Tilt Current Meter: Inexpensive Near-Bottom Current Measurements Based on Drag Principle with Coastal Applications *Eos Trans. AGU, 91*(26), Ocean Sci. Meet. Suppl., Abstract PO25C-13

Images

There are thousands of images posted on http://emolt.org. Given the new camera project, there are also thousands of images posted at http://www.flickr.com/photos/emoltlobcam. There is also a collection of drifter animations posted at http://gisweb.wh.whoi.edu/ioos/drift/animations.html

Future research

Given that more drifters were deployed in 2011 than any previous year, it is unlikely that the drifter project, first funded by NEC in 2004, is going away. We do not expect additional seed funding from NEC but, given the results thus far, we hope to be able to secure routine operational funding from other NOAA sources such as ECOHAB or IOOS. There is also some chance we may be able to obtain funding indirectly from Ocean Observatory Initiative (OOI) or other NSF initiatives. There are indications that our colleagues in the Middle Atlantic Bight may be looking for drifter data for both model and CODAR validation.

In addition to more drifter deployments, we hope to continue the development of the bottom current meter (eMOLT Phase VIII). Our proposal to NOAA's Advanced Technology Working Group to add a digital compass to the instrument has been funded and will allow us to better resolve the direction of current in the coming year. As noted above, we hope to also distribute more digital cameras to our lobstermen in an effort to monitor our instrument performance as well as the lobster catch activity and better statistics on how the traps are landing.

We continue to make improvements to the presentation of our results on the web. The most recent additions are pages that allow teachers and students to document their deployments and enter the necessary metadata in a standardize way. There are also a variety of googlemap presentations of the tracks. The new drifter website is at: http://gisweb.wh.whoi.edu/cgi-bin/ioos/drift/driftTable.cgi Similarly, the results associated with the new bottom-current meter is posted at: http://www.nefsc.noaa.gov/epd/ocean/MainPage/tilt/shtcm.html where there are links to all the time series data collected thus far. Web presentations will continue to evolve as new display methods become available. Flash animations, for example, are now posted and provide far more effective visualization of both modeled and observed drifter tracks.

In 2011, we submitted a proposal to NOAA's Office of Aquaculture. While we were unsuccessful, we hope to try again in the future asking to install our instrumentation on local oyster farms in order to investigate the relationship between current and shell growth. As part of this work, we will propose to continue our assessment of local circulation model output in these areas.

Most importantly, we hope to make our bottom temperature data more realtime in the future. As noted above, due to a collaboration with the NE Cooperative Research Program at NEFSC, we now have a prototype temperature probe that automatically downloads data when it is hauled on deck via a wireless connection. This instrument shows great promise in eventually sending data from a fishing vessel to a cell phone or satellite. We have already started proposals elsewhere to enhance the NEC-funded current meter so that it too will telemeter its data in near real-time.

Acknowledgements

We would like to acknowledge the help of two students from the Shandong University of Science and Technology, Xiuling Wu and Huanxin Xu, for their help in our transition from MATLAB to PYTHON code. In the past few years, they have written thousands of lines of code. Despite having little experience with this language prior to arriving from China, they have helped us build a tools we need to continue in an open source environment. We also acknowledge the many students, teachers, and fishermen who have helped us build instruments and collect data. We acknowledge local numerical modelers and, in particular, the folks at UMASS Dartmouth SMAST NECOFS lab for allowing us access to their modeled fields. Finally, we are most appreciative of NEC in getting us started by providing the seed money to build the eMOLT system. We intend to maintain it for years to come.